Chapter 1

Introduction

In the chapters that follow, we present our design to accelerate and store polarized protons in RHIC, with the level of polarization, luminosity, and control of systematic errors required by the approved RHIC spin physics program. Below, we provide an overview of the physics to be studied using RHIC with polarized proton beams, and a brief description of the accelerator systems required for the project.

1.1 Physics Motivation

The Relativistic Heavy Ion Collider (RHIC)[1] at Brookhaven will collide gold nuclei to create very high density and temperature, and explore a regime of the possible deconfinement of quarks and gluons in the colliding nuclei. RHIC will also collide intense beams of polarized protons[2], reaching transverse energies where the protons scatter as beams of polarized quarks and gluons.

The polarized proton program at RHIC will open a unique laboratory. W and Z boson production are expected to maximally violate parity. This parity violation will be used to measure the quark polarization in polarized protons by individual flavor: W^+ production will give the u and $\bar{d}$ quark polarization, and W^- production will give d and $\bar{u}$ polarization in the polarized proton. Direct photon production with colliding polarized protons measures the gluon polarization in the polarized proton. These examples use perturbative QCD to explore the spin structure of the proton. Searches for other parity violation is sensitive to new physics. For example, a parity violation can arise from interactions from quarks with substructure, or from a new right-handed Z boson.

RHIC provides an optimal energy range for this study. Collisions may be studied from 50 to 500 GeV center of mass energy. For these energies the transverse momentum reach is well into the perturbative QCD regime. For example, jets will be studied with $p_T = 50$ GeV/c. At the highest energy, W and Z will be copiously produced. At the same time, the fraction of the proton energy carried by the quarks and gluons that collide will be relatively large, typically $x > 0.1$. For large momentum fraction, SLAC and CERN have measured that the quarks that participate in the collisions will have large polarization. When we are investigating, for example, gluon polarization using direct photon production, the asymmetry that

we measure is proportional to the product of the gluon polarization and the quark polarization. If the quark polarization is high, we are more sensitive to the gluon polarization.

The RHIC polarized proton luminosity is expected to be high: 2×10^{32} cm^{-2}s^{-1} for $\sqrt{s} = 500$ GeV. This is possible because of the compression of the protons in the Booster/AGS into bunches which are then stored in RHIC. The luminosity requires an emittance of 20 π mm mrad (95%, normalized), and this is an important issue in the approaches used to maintain polarization through acceleration in the AGS. The major RHIC accelerator and beam parameters for achieving polarized proton collisions are found in Table 1.1.

Parameter	
Peak c.m. energy	500 GeV
Initial luminosity	2×10^{32}cm^{-2}sec^{-1}
Interactions per	
crossing (60 mb)	1
Protons per bunch	2×10^{11}
Bunches per ring	120
Normalized emittance (95%)	20 π mm mrad
β^*	1 m
Average polarization	70%
Stable Spin direction	
at Interaction Point	vert. or long.
RF voltage per turn	6 MV
RF harmonic number	2520
Long. emittance (95%)	0.3 eV sec
Beam Momentum Spread	2.6×10^{-4}
Beam-beam tune spread (per IR)	0.007

Table 1.1: RHIC Spin Accelerator Parameters.

Several experiments have used polarized electrons or muons scattering from polarized protons to study the quark spin contribution to the proton. These experiments have found that when quarks carry most of the momentum of a polarized proton, they are also very polarized.[3] This is important for the RHIC sensitivity to the gluon polarization. The experiments have also found, however, that the average contribution of the quarks to the proton spin is small: $27\% \pm 10\%$ from E143 proton data and $22\% \pm 14\%$ from SMC proton data. The remaining contribution must be from gluons, angular momentum, or both. A number of programs have been proposed to measure the gluon polarization: COMPASS at CERN, SLAC, HERA, and RHIC. The process and sensitivity for the proposals are given in Tables 1.2 and 1.3.[4] The RHIC program is more sensitive to the gluon polarization than the others. If the gluons in a polarized proton are significantly polarized, one would want to understand the origin of this nonintuitive result.

The electron and muon programs measure an average quark contribution to the proton spin, without distinguishing the quark flavor (semi-inclusive scattering can separate flavor, with a severe penalty for

Experiments Planned To Measure ΔG			
EXPERIMENT	**SLAC**	**COMPASS @CERN**	**RHIC**
Quantity Measured	$\mathcal{A}_{\vec{\gamma}\vec{N}}^{c\bar{c}} + \mathcal{A}_{\vec{\gamma}\vec{N}}^{J/\psi} + \mathcal{A}_{\vec{\gamma}\vec{N}}^{Bet-Heit} + ...$ 4 (e$^-$ beam) energies	$\mathcal{A}_{\vec{\mu}\vec{N}}^{\mu c\bar{c}}$ up to 4 ν bins	$\mathcal{A}_{\vec{p}\vec{p}}^{\gamma jet}$ several x_G bins
Processes	$\vec{\gamma} + \vec{N} \to c\bar{c}$ $c \to \mu$ (BR= 8%) $\mu^+\mu^-$ & μ (high p_T)	$\vec{\mu} + \vec{N} \to \vec{\mu} + c\bar{c}$ $c \to D^0 \to K^-\pi^+$ (BR= 4%) Also $D^{*+} \to \pi^+ D^0$	$\vec{p} + \vec{p} \to \gamma$+jet
Kinematical range	Bremsstrahlung $\gamma's$, Q$^2 = 0$ $E_\gamma^{min} < E_\gamma < 48.5$ $0.10 < x_G < 0.25$	Quasi-real $\gamma's$ Q$^2 \approx 0$ $35 < \nu < 85$ $0.06 < x_G < 0.35$	 $0.0 < x_G < 0.4$
Theoretical Basis & Uncertainties	LO available, NLO in progress For $\vec{\gamma} + \vec{N} \to c\bar{c}$ c quark mass uncertainty	 For $\vec{\mu} + \vec{N} \to \vec{\mu} + c\bar{c}$ 	For $qg \to \gamma(qjet)$ Background from $q\bar{q} \to \gamma(gjet)$; Should know Δq
Kinematical Constraints	Cuts on $p_T^{\mu\mu'}, M^{\mu\mu'}$ and p_T^μ	Events at D^0 mass	$5 < p_T < 30$
Experimental Difficulties	Disentangle $\mathcal{A}_\gamma^{c\bar{c}}$ from background asymmetry	Combinatorial background from K/π $B/S \approx 4$	Identify direct $\gamma's$; Contamination from $\pi^o \to \gamma\gamma$
Statistical Error on $\mathcal{A}$	$\delta\mathcal{A}_\gamma^{c\bar{c}} = 0.01 - 0.02$	$\delta\mathcal{A}_\gamma^{\mu c\bar{c}} = 0.05$ for full data	$\delta\mathcal{A} = 0.002 - 0.04$
on $\Delta G/G$	$\delta(\Delta G/G) = 0.02 - 0.08$	$\delta < \Delta G/G > = 0.10$	$\delta(\Delta G/G) = 0.01 - 0.3$
Systematics	Contribution of backgrounds and randoms to $\mathcal{A}_\gamma^{c\bar{c}}$	Beam & target polarizations $\pm 4\%$	Beam polarization $\pm 6\%$ False asymmetries small
Status	pre-proposal stage	Approved by SPSLC	RHIC complete with Siberian snakes in 1999
Time scale	< Year 2000	$\geq$ Year 2000	Accelerator and detectors ready after year 2000
Remarks	Data taking : few months	Apparatus shared with hadron program	Apparatus shared with heavy ion program

Table 1.2: Gluon polarization experimental proposals.

EXPERIMENT	POLARIZED HERA		HERA-N
	Inclusive	**Exclusive (2-jets)**	
Quantity Measured	$g_1^p(x)$ wide x-Q^2 range	$\mathcal{A}_{\vec{e}\vec{p}}^{e(2\ jets)}$ several x_G bins	$\mathcal{A}_{\vec{p}\vec{N}}^{\gamma jet}$ & $\mathcal{A}_{\vec{p}\vec{N}}^{J/\psi jet}$ several x_G bins
Process	Polarized inclusive e,p DIS	$\vec{e} + \vec{p} \to 2$ jets Photon-Gluon-Fusion $(80-90\%)$	$\vec{p} + \vec{N} \to \gamma(J/\psi) + jet$ Internal $\vec{N}$ target
Kinematics Range	$1.8 < Q^2 < (1.8 \times 10^4)$ $(5.5 \times 10^{-5}) < x < 1$	$5 < Q_G^2 < 100, \sqrt{s_{ij}} > 10$ $0.002 < x_G < 0.2$	$0.1 < x_G < 0.4$
Theoretical Basis & Uncertainties	$\Delta G(x, Q^2)$ & $\int \Delta G$ from pQCD at NLO minimum uncertainties	LO calculations for $\mathcal{A}_{\vec{e}\vec{p}}^{e(2\ jets)}$ Lack of NLO calculations for polarized cross sections and for Monte Carlo	Onset of pQCD for $\gamma + (X)$; pQCD for $J/\psi + (X)$ Should know Δq
Kinematical Constraints	$y > 0.01\ \theta_{e'} > 3^o$ $Q^2 > 1, E_{e'} > 5$	$p_T > 5,\ \|\eta\| < 2.8$ $0.3 < y < 0.8$	$2 \leq p_T \leq 8$ $-1.5 \leq \eta \leq +1.5$
Experimental Problems	Polarization of 820 GeV protons in HERA and measurement of proton polarization		
		Gluon Compton 2-jet background	Identify direct $\gamma' s$
Statistical Error on $\mathcal{A}$	for $\mathcal{L} = 200$ $\delta\mathcal{A} = 10^{-3}$ to 0.1	for $\mathcal{L} = 200$ $\mathcal{A} =$ few%, $\delta\mathcal{A} < (0.2\ to\ 1\%)$	
on $\Delta G/G$	Relative error on $\int \Delta G$ 25(20)% with $\mathcal{L} = 200(1000)$	$\delta(\Delta G/G)$ $0.10 - 0.50$	for $\mathcal{L} = 250$ $\delta(\Delta G/G) < 0.1$
Systematics	Measurement of P_e, P_p ($\pm 5\%$). False asymmetries small since can provide any sign of P_p for any bunch, and with a spin rotator can change P_p sign of all bunches.		
Status	Study of polarized protons at HERA; pre-proposal stage		
Time Scale	$\geq$ Year 2003 HERA operational with 27 GeV $\vec{e}$; H1 & ZEUS detectors operational		
Remarks Conclusions	Low x behavior of $g_1^p(x, Q^2)$ of great interest	x_G is directly measured over a wide kinematic range	Need (new) HERA-B type detector

<div align="center">Experiments Planned To Measure ΔG</div>

Table 1.3: Gluon polarization experimental proposals (cont'd).

rate; the CERN experiment SMC has done this). With both proton and neutron results, the s-quark contribution has been isolated to be $-10\% \pm 4\%$ (E143) of the proton spin.[3] This implies that the sea quarks may have significant polarization. The RHIC program will measure $\bar{u}$ and $\bar{d}$ polarization, as well as u and d-quark polarization using parity violation in W production.

The RHIC program will measure asymmetries in the production of photons, jets, and W and Z bosons with longitudinal polarization and with transverse polarization. Longitudinal polarization is required for the proton spin content studies discussed above. The asymmetries are a difference in production between left and right handed protons divided by the sum, normalized by the beam polarizations. For parity violation, we compare the production with one beam polarized, with the other beam unpolarized (or summing over both polarization states of the other beam):

$$A_L = \frac{1}{P} \frac{N_+ - N_-}{N_+ + N_-}.$$

N_+ and N_- represent the number of particles observed from right and left handed polarized protons, respectively, normalized for luminosity. P is the polarization of the beam. The error in the asymmetry is proportional to $1/\sqrt{N_+ + N_-}$ and to $1/P$. The RHIC Spin proposal is based on 70% polarization. If the polarization were smaller, say 50%, the experiments would need to run twice as long to obtain the proposed sensitivity for parity violation experiments. The direct photon experiments measure a two-spin asymmetry,

$$A_{LL} = \frac{1}{P^2} \frac{N_{++} - N_{+-}}{N_{++} + N_{+-}}.$$

N_{+-} represents the production for right handed polarized protons colliding with left handed polarized protons. Both beams have the polarization P. For this case, a 50% beam polarization would lead to a four times longer run to obtain the proposed sensitivity. Similar arguments point to the importance of excellent knowledge of the beam polarization. We expect to know the beam polarization to $\pm 7\%$ of itself.

The asymmetry is proportional to the polarization of the quarks or gluons that collide and to the analyzing power of the subprocess:

$$A_{LL} = \frac{\Delta a(x_a)}{a} \times \frac{\Delta b(x_b)}{b} \times \hat{a}\,(a + b \rightarrow c + d)\,.$$

$\Delta a(x_a)/a$ is the polarization of quark or gluon a, which carries the fraction x_a of the proton momentum, for a proton polarization of 100%. b represents the other colliding quark or gluon. Here we assume that only one subprocess is involved. The analyzing power of the subprocess is typically of order 1. For direct photon production, which is dominated by gluon-quark scattering, the analyzing power for the subprocess is $\hat{a} = 0.6$ for production near $90°$. The large subprocess analyzing power is a result of angular momentum conservation. We see that to make a sensitive measurement of the polarization of the gluon, say $\Delta a/a$, it helps if the polarization of the quark b is large. This is the case for $x_b > 0.1$, which is true for the RHIC energy range.

The measured raw asymmetry is the product of the beam polarizations, the quark/gluon polarizations, and the subprocess analyzing power. These raw asymmetries will typically be small, and the measurement will need excellent control of systematic errors such as different detection efficiency for different beam polarization sign. These systematic errors will need to be controlled to reach proposed sensitivity.

1.2   Spin Dynamics and Siberian Snakes

To achieve high energy polarized proton collisions polarized beams first have to be accelerated which requires an understanding of the evolution of spin during acceleration and the tools to control it. The evolution of the spin direction of a beam of polarized protons in external magnetic fields such as exist in a circular accelerator is governed by the Thomas-BMT equation[5],

$$\frac{d\vec{P}}{dt} = -\left(\frac{e}{\gamma m}\right)\left[G\gamma\vec{B}_\perp + (1+G)\,\vec{B}_\parallel\right] \times \vec{P}$$

where the polarization vector $\vec{P}$ is expressed in the frame that moves with the particle. This simple precession equation is very similar to the Lorentz force equation which governs the evolution of the orbital motion in an external magnetic field:

$$\frac{d\vec{v}}{dt} = -\left(\frac{e}{\gamma m}\right)\left[\vec{B}_\perp\right] \times \vec{v}.$$

From comparing these two equations it can readily be seen that, in a pure vertical field, the spin rotates $G\gamma$ times faster than the orbital motion. Here $G = 1.7928$ is the anomalous magnetic moment of the proton and $\gamma = E/m$. In this case the factor $G\gamma$ then gives the number of full spin precessions for every full revolution, a number which also called the spin tune ν_{sp}. At top RHIC energies this number reaches about 400. The Thomas-BMT equation also shows that at low energies ($\gamma \approx 1$) longitudinal fields $\vec{B}_\parallel$ can be quite effective in manipulating the spin motion, but at high energies transverse fields $\vec{B}_\perp$ need to be used to have any effect beyond the always present vertical holding field.

The acceleration of polarized beams in circular accelerators is complicated by the presence of numerous depolarizing resonances. During acceleration, a depolarizing resonance is crossed whenever the spin precession frequency equals the frequency with which spin-perturbing magnetic fields are encountered. There are two main types of depolarizing resonances corresponding to the possible sources of such fields: imperfection resonances, which are driven by magnet errors and misalignments, and intrinsic resonances, driven by the focusing fields.

The resonance conditions are usually expressed in terms of the spin tune ν_{sp}. For an ideal planar accelerator, where orbiting particles experience only the vertical guide field, the spin tune is equal to $G\gamma$, as stated earlier. The resonance condition for imperfection depolarizing resonances arises when $\nu_{sp} = G\gamma = n$, where n is an integer. Imperfection resonances are therefore separated by only 523 MeV energy steps. The condition for intrinsic resonances is $\nu_{sp} = G\gamma = kP \pm \nu_y$, where k is an integer, ν_y is the vertical betatron

tune and P is the superperiodicity. For example at the Brookhaven AGS, $P = 12$ and $\nu_y \approx 8.8$. For most of the time during the acceleration cycle, the precession axis, or stable spin direction, coincides with the main vertical magnetic field. Close to a resonance, the stable spin direction is perturbed away from the vertical direction by the resonance driving fields. When a polarized beam is accelerated through an isolated resonance, the final polarization can be calculated analytically[6] and is given by

$$P_f/P_i = 2e^{-\frac{\pi|\epsilon|^2}{2\alpha}} - 1,$$

where P_i and P_f are the polarizations before and after the resonance crossing, respectively, ϵ is the resonance strength obtained from the spin rotation of the driving fields, and α is the change of the spin tune per radian of the orbit angle. When the beam is slowly ($\alpha \ll |\epsilon|^2$) accelerated through the resonance, the spin vector will adiabatically follow the stable spin direction resulting in spin flip. However, for a faster acceleration rate partial depolarization or partial spin flip will occur. Traditionally, the intrinsic resonances are overcome by using a betatron tune jump, which effectively makes α large, and the imperfection resonances are overcome with the harmonic corrections of the vertical orbit to reduce the resonance strength ϵ [7]. At high energy, these traditional methods become difficult and tedious.

By introducing a 'Siberian Snake' [8], which generates a 180° spin rotation about a horizontal axis, the stable spin direction remains unperturbed at all times as long as the spin rotation from the Siberian Snake is much larger than the spin rotation due to the resonance driving fields. Therefore the beam polarization is preserved during acceleration. An alternative way to describe the effect of the Siberian Snake comes from the observation that the spin tune with the Snake is a half-integer and energy independent. Therefore, neither imperfection nor intrinsic resonance conditions can ever be met as long as the betatron tune is different from a half-integer.

Such a spin rotator is traditionally constructed by using either solenoidal magnets or a sequence of interleaved horizontal and vertical dipole magnets producing only a local orbit distortion. Since the orbit distortion is inversely proportional to the momentum of the particle, such a dipole snake is particularly effective for high-energy accelerators, e.g. energies above about 30 GeV. For lower-energy synchrotrons, such as the Brookhaven AGS with weaker depolarizing resonances, a partial snake[9], which rotates the spin by less than 180°, is sufficient to keep the stable spin direction unperturbed at the imperfection resonances. A 5% (i.e., 9° rotator) partial snake has been successfully used in the AGS as described in Section 2.2.

1.3 Polarized Proton Acceleration at RHIC

By using Siberian Snakes the stage is set for the acceleration of polarized proton beams to much higher energies. Polarized protons from the AGS are injected into the two RHIC rings to allow collisions at center of mass energies up to 500 GeV with both beams polarized. Fig. 1.1 shows the lay-out of the Brookhaven accelerator complex highlighting the components required for polarized beam acceleration.
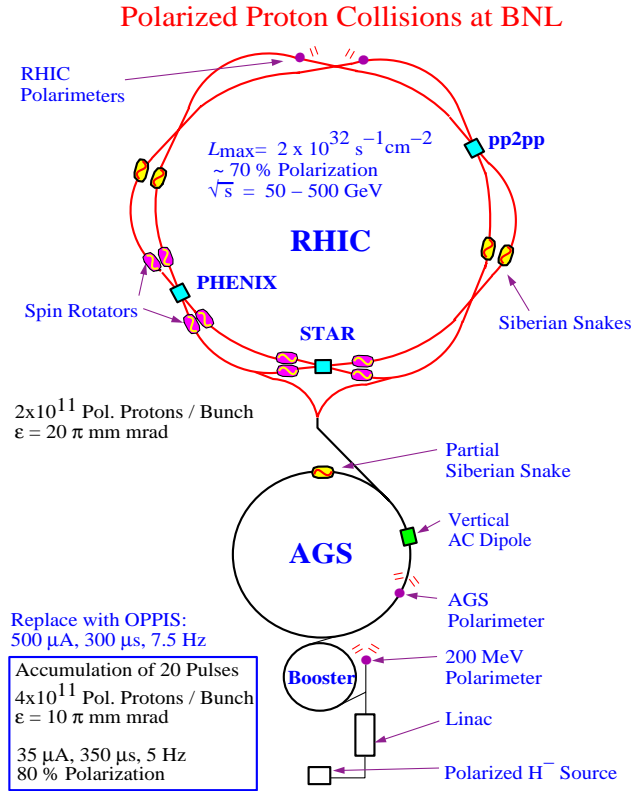
Figure 1.1: The Brookhaven hadron facility complex, which includes the AGS Booster, the AGS, and RHIC. The RHIC spin project will install two snakes per ring with four spin rotators per detector for achieving helicity-spin experiments.

To maintain polarization during the acceleration process, two full Siberian Snakes are inserted on opposite sides of the RHIC lattice for each of the two counter-rotating rings. In addition to these Snakes other magnetic components – spin rotators – are located on each side of the two major interaction points (again, for each ring) which allow the spin orientation to be altered from the vertical plane to the longitudinal plane. These devices are the primary magnetic components of the polarized beam project at RHIC. In addition, "spin flip" devices will be inserted to allow for the manipulation of the spin through $180°$ during a store, as well as polarimetry instrumentation. Fig. 1.2 shows all the major components that are required for the acceleration of polarized beams to RHIC top energy. The feasibility of accelerating polarized protons in RHIC was the basis of the proposal the RHIC Spin Collaboration (RSC) submitted to the Brookhaven PAC in October 1992 [10] and approved in 1993.

A summary list of the major hardware components for the acceleration of polarized protons in RHIC is provided in Table 1.4. The major elements required for this project are the superconducting magnets for the Siberian Snakes and the Spin Rotators. Each Siberian Snake consists of a set of four superconducting
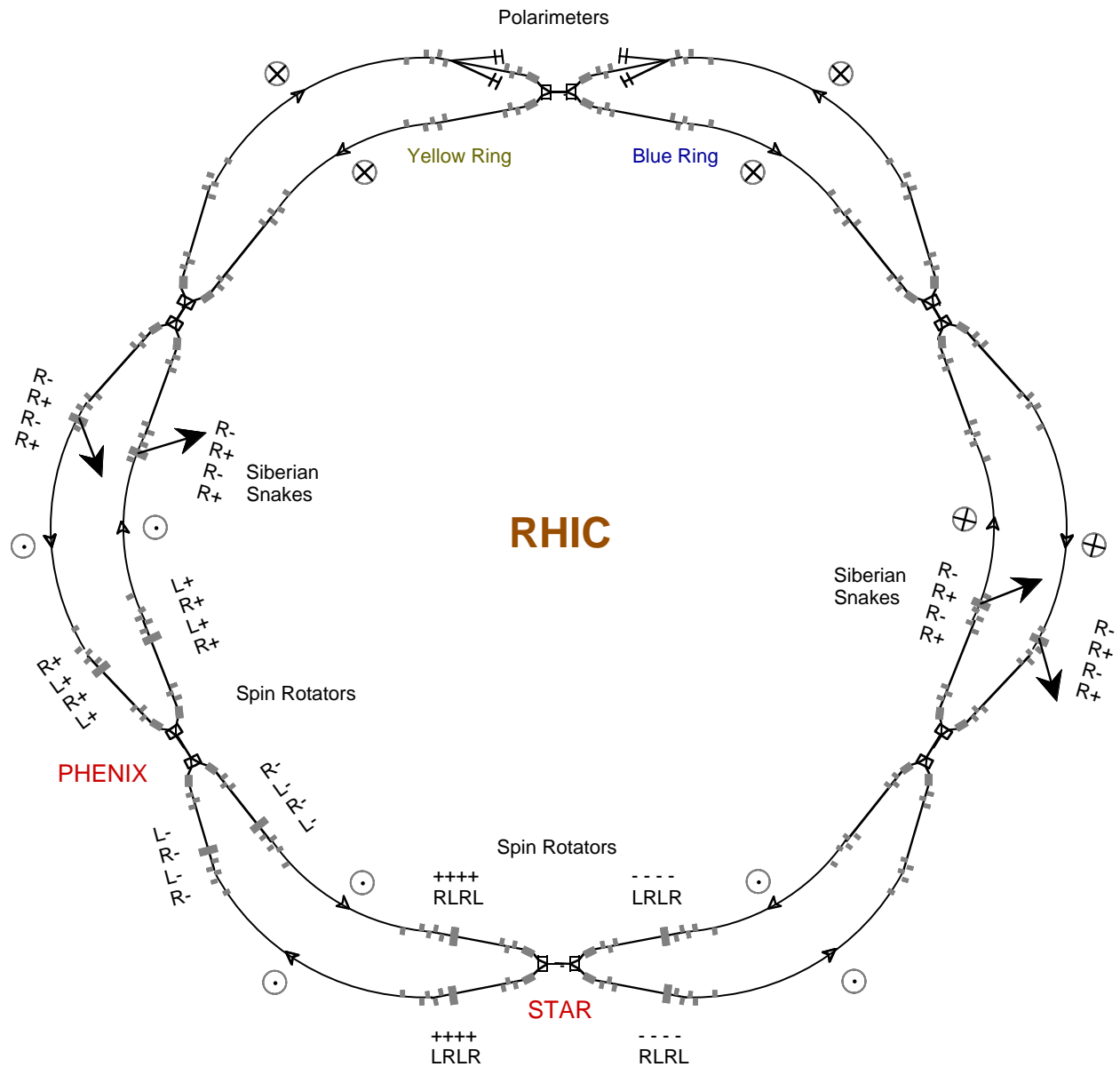
Figure 1.2: View of RHIC overemphasizing the interaction regions to show the location of the Siberian Snakes and the spin rotators placed around the collider experiments STAR and PHENIX. Also shown are the polarization directions around the rings and around the detectors for collisions with longitudinal polarization.

Item	No.
Snakes	4
Helical Dipoles	16
Rotators	8
Helical Dipoles	32
Spin Flippers	2
Polarimeters	2
Toroids	16

Table 1.4: RHIC Polarized Beams Systems Hardware

helical dipole magnets. The magnets will be capable of producing a central field of up to 4 T which spirals through 360° over a length of approximately 2.4 m. Four such magnets, each independently powered, can generate a spin rotation from vertically up (the nominal stable spin direction for the synchrotron) to vertically down, with no net excursions of the particle trajectory. This is the function of the Snake. The Spin Rotator is similarly constructed; by altering the "handedness" of two of the helical magnets, and using slightly different fields, the spin can be made to rotate from the vertical to the longitudinal direction.

With one or two Snakes all depolarizing resonances should be avoided since the spin tune is a half-integer independent of energy. However, if the spin disturbance from small horizontal fields is adding up sufficiently between the Snakes, depolarization can still occur. This is most pronounced when the spin rotation from all the focusing fields add up coherently which is the case at the strongest intrinsic resonances. At RHIC two Snakes can still cope with the strongest intrinsic resonance.

To provide RHIC with polarized beams capability, a total of 4 Snakes and 8 Rotators are required. Thus, 48 individual full-helical dipole magnets will be constructed. The four magnets needed to create one Snake or one Rotator will be mounted inside of a standard RHIC Dipole Magnet cryostat. Since it is desirable to independently power the four magnets within the cryostat, the required current should be minimized in order to keep the heat leak due to the power leads as small as possible. Thus, hundreds of turns are required. This poses a technical challenge to the construction of these high-field magnets. The parameters of the Snake and Rotator helical dipole magnets are shown in Tables 1.5 and 1.6. The field strengths of the Snake magnets are held constant during the acceleration process, while the appropriate fields in the Rotator magnets are beam energy dependent, and are only powered during beam storage.

During the course of a polarized colliding beams experiment, it is desirable to adiabatically reverse the direction of the spin to eliminate the possibility of systematic errors. By introducing an oscillating field on resonance with the natural spin precession frequency, such a "spin flip" can occur. A discussion of the hardware used to perform this task is described in Section 7.4. In addition to their use for the experiments, the spin flip devices can be used to accurately measure the spin precession frequency (or, "spin tune") and so will be used during commissioning of the Snakes.

Helical Magnets			Field [Tesla]
	length[m]	handedness	
1	2.4	righthanded	1.19
2	2.4	righthanded	−3.86
3	2.4	righthanded	3.86
4	2.4	righthanded	−1.19

Table 1.5: Parameters of the Siberian Snake magnets

Helical Magnets			Field [Tesla]	
	length[m]	handedness	@ 25 GeV	@ 250 GeV
1	2.4	righthanded	2.05	3.38
2	2.4	lefthanded	2.65	3.14
3	2.4	righthanded	2.65	3.14
4	2.4	lefthanded	2.05	3.38

Table 1.6: Parameters of the Spin Rotator magnets

Another major component is the instrumentation used to measure the beam polarization. Polarimetry has two functions: relative and absolute polarization measurements. Relative measurements may use a spin-sensitive process which has a high rate, but is uncalibrated. Our plan for RHIC is to use pion production as a relative polarimeter. This process is calibrated at two energies, 22 and 200 GeV/c. At 22 GeV/c the calibration was *pp* elastic scattering, where the analyzing power is known through polarized target experiments. At 200 GeV/c a beam of known polarization, obtained from Λ decay, was used to measure the absolute analyzing power of pion production. We will calibrate our polarimeters, one for each ring, by a process of accelerating to either 23 or 200 GeV to obtain the absolute beam polarization, then accelerating/decelerating to other energies, measuring the analyzing power, followed by a final measurement of beam polarization at the calibration energy. A separate experiment will also use proton-Carbon elastic scattering in the Coulomb-nuclear interference (CNI) region to measure the polarization, with the assumption that hadronic spin-flip amplitudes are not important. This provides a second relative polarimeter and a check on the pion results. Finally, Italian collaborators have applied for funds to develop an intense polarized proton jet target. The polarization of the jet would be known, and a process such as CNI proton-proton scattering could be calibrated with the jet. Our goal is absolute polarization to $\Delta P/P = \pm 5\%$. The pion polarimeter is calibrated at 22 GeV/c to $\pm 10\%$ and at 200 GeV/c to $\pm 7\%$. The pion polarimeters use carbon ribbon targets in each beam, followed by spectrometers to observe pion production with spin-sensitive kinematics. Details of the polarimeter system can be found in Chapter 8.

The other various accelerator systems which are part of the project include power supplies, controls, and installation. Some modifications to the RHIC cryogenic hardware in the tunnel is necessary to provide the

proper interface to the Rotators which are located in otherwise warm straight sections near the interaction points. The Snakes are to be located in cold straight sections which are already the appropriate length for a standard RHIC Dipole Magnet and hence no tunnel hardware modifications are necessary. As much as possible, standard RHIC accelerator systems hardware will be utilized throughout the project.

1.4   Cost and Schedule

Table 1.7 gives a summary of the original project Cost Estimate, including EDIA, performed in early 1997. An overall contingency of 20% was used for the major categories.

Snakes/Rotators	$4.5M
Magnet Electrical System	$0.4M
Polarimeters	$1.3M
Cryogenics	$0.2M
Subtotal:	$6.4M
EDIA	$3.1M
General Administration	$0.5M
TOTAL:	**$10.0M**

Table 1.7: Polarized Beam Accelerator Cost Summary

The major funds for the RHIC spin project are being provided by The Institute of Physical and Chemical Research (RIKEN), Saitama, Japan. The project is being funded in three phases, with the first two phases devoted to prototype development and to the development of system design requirements. Phase III contains the funding for construction, installation, and commissioning of the final systems hardware. A memorandum of understanding between RIKEN and BNL was signed on September 25, 1995, and Phases I and II have been successfully completed. Major milestones for the project are listed in Table 1.8. The

First Prototype Magnets Tested	December 1996
Final Design Report Complete	June 1998
First Helical Dipole Complete	September 1998
2 Snakes, 1 Polarimeter Installed	September 1999
Polarized Beam in 1 Ring	>October 1999
All Snakes/Rot./Pol. Installed	September 2000
Polarized Beam in 2 Rings	September 2000
First Spin Physics Run in RHIC	>October 2000

Table 1.8: Polarized Beam Accelerator Milestone Summary

schedule dates listed are consistent with having a 100 GeV polarized proton run during the second year of RHIC operation.